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On the structure of explanatory unification: The case of geographical economics

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Abstract: A newly emerged field within economics, known as geographical economics claims to have provided a unified approach to the study of spatial agglomerations at different spatial scales by showing how these can be traced back to the same basic economic mechanisms. We analyze this contemporary episode of explanatory unification in relation to major philosophical accounts of unification. In particular, we examine the role of argument patterns in unifying derivations, the role of ontological convictions and mathematical structures in shaping unification, the distinction between derivational and ontological unification, the issue of how explanation and unification relate and finally the idea that unification comes in degrees.

Keywords: Unification; Explanation; Mathematics; Mechanism; Geographical Economics

1. Introduction

This is a case study in the philosophy of economics that seeks to contribute to the investigation into explanatory unification in the general philosophy of science. We believe our examination of the contested notion of unification in relation to the contested discipline of economics will cast illumination on both. Our primary focus here is on unification.

Amongst practising scientists, unification is widely perceived as a methodological virtue that should be pursued, and eventual achievements of unification are to be celebrated. Philosophers of science have long recognized this feature of scientific practice and have sought to develop accounts of it. They are accounts of what it is to "explain much by little" and of how to assess such explanatory unifications. Most of the illustrations and case studies provided by philosophers come from the natural sciences, mainly physics and biology (e.g. Kitcher 1989; Morrison 2000). Few philosophical studies have been concerned with unification in the social sciences (see, however, Kincaid 1997; Mäki 1990, 2001, 2002, fortcoming). This is a shortcoming, as unification is no less of a pressing issue in the social sciences. The urge to unify has shaped much of social scientific theory formation, and the dream of a unified social science has given rise to a long history of research and debate that is very much alive today. Furthermore, given that unification does not seem entirely uniform across fields of scientific inquiry, the empirical effort of identifying the varying specific features of attempted or achieved unifications in different domains of inquiry becomes essential for understanding unification. Our study suggests that none of the available philosophical accounts of explanatory unification is alone able to do justice to this variation.

We offer a detailed examination of a contemporary episode of explanatory unification in the social sciences. Thus, we follow the tradition of looking at the actual practice of science to gain insights for the philosophy of science. Our case study deals with a newly emerged sub-field of economics, known as *Geographical Economics* (also as new economic geography; GeoEcon henceforth). After Paul Krugman's seminal 1991 article, GeoEcon started taking shape relatively fast. Mainly thanks to the appearance of three monographs (Fujita et al. 1999; Fujita and Thisse 2002; Baldwin et al. 2003), and a textbook (Brakman et al. 2001), GeoEcon "has now reached its first theoretical consolidation" (Ottaviano and Robert-Nicoud 2006). Furthermore, GeoEcon is gaining increasing currency in the policy arena, from urban and rural policy to development and international policy (see for instance Kanbur and Venables 2007). GeoEcon thus seems both ripe and relevant for a closer philosophical scrutiny.

The development of GeoEcon is the result of successive applications of a core set of ideas to a number of disparate classes of spatial phenomena that were previously either neglected by economics or studied by separate fields. In particular, GeoEcon alleges to explain the uneven spatial distribution of economic activity at different levels of spatial aggregation as the result of the same kinds of economic mechanism. More specifically, it provides a unified framework for the explanation of a variety of kinds of agglomeration

phenomena such as industry clusters, core-periphery patterns among countries and regions, cities and systems of cities, patterns of international trade and specialization, and the causes of economic growth and development. The unification of these classes of empirical phenomena then paves the way for the long-awaited unification of location theory and trade theory (Ohlin 1933). The proponents of GeoEcon theory proudly identify its unificatory capacity as a remarkable virtue. A commentator explicitly compares the trends towards unification in physics with unification in GeoEcon: "Since the 1970's the top item on the agenda of theoretical physics has been to unify general relativity theory and quantum mechanics into a theory of quantum gravity […] A main purpose of this book [viz. Fujita et al. 1999] is to demonstrate that many of the stylized facts of urban and regional economics […] can be derived from a set of common assumptions." (Urban 2001: 151)

We analyse the GeoEcon unification with two goals in mind. One is to offer an account of the practice of unification in GeoEcon. The other is to use this case to generate critical reflections on philosophical theories of unification. We ask what exactly is going on in GeoEcon when the practitioners say that what they do is unification; and we use our empirical discoveries to assess key elements in some of the major contemporary philosophical accounts of unification.

As a first step, we utilize Kitcher's (1981, 1989) model of unification in terms of argument patterns to characterize the structure of unification in GeoEcon. We then examine four further issues. The first issue relates to Margaret Morrison's (2000) observation that in most cases of unification in physics and biology, the unifying theory embodies a mathematical structure that plays a prominent role in the process of unification, sometimes at the expense of ontology. We identify the respective roles of mathematics and of ontological conviction in driving the GeoEcon unification. Second, we take issue with Kitcher's account of unification that implies that unification (and explanation) is a matter of inference and derivation. By employing a distinction between derivational and ontological unification (Mäki 1990, 2001, forthcoming), we examine whether unification in GeoEcon is exclusively a matter of derivation, or also an attempt to reveal an underlying ontic unity between apparently diverse phenomena.[1] Our third issue is concerned with how unification relates to explanation. Kitcher's view is that explanation is unification, while many others take issue with this and argue instead that unification and explanation are logically and conceptually separate. Morrison (2000) even claims that the two are at odds with one another. We show which view fits better the practice of GeoEcon unification. Finally, our last issue attends to a special feature of the GeoEcon unification that is not captured by any of the traditional accounts of unification, namely that the unifying mechanism in GeoEcon is neither the only nor the main mechanism in operation in bringing about diverse agglomeration phenomena. This attests to the flexible use of 'unification' in scientific practice.

[1] In what follows, we use the term 'unification' to refer to the theoretical process whereby apparently diverse phenomena are brought under a unified explanatory framework, and the term 'ontic unity', to refer to the relations that tie the phenomena together.

2. Unification in terms of argument patterns

According to Kitcher, explanatory unification is a matter of applying the same "argument pattern" or "pattern of derivation" to derive descriptions of different kinds of explanandum phenomena (Kitcher 1981, 1989). This aspect of Kitcher's account seems to get close to the practice of unification in economics more generally: economists working within the constrained maximization framework easily recognise the idea of a common argument pattern applied again and again in different fields of research (Mäki 2001). In this section we show that GeoEcon is largely in line with the rest of economics in this respect. This is so even though economists do not use the vocabulary of 'argument pattern' or 'pattern of derivation' - they rather talk about 'models' and 'derivations' and 'proofs'. In economists' modelling exercises, a specific model is constructed using a general model type as a template, and then derivations are performed within the model, exploiting its inferential resources. Sometimes the accomplishments of these activities are called explanations. This is in line with Kitcher's own view that what he calls "a general model type" is akin to a general argument pattern (while the latter phrase helps highlight the explanatory uses of the model type; see Kitcher 1993: 45, n63).

An *argument pattern* includes sets of schematic sentences that are expressions in which most if not all non-logical expressions are replaced with dummy letters. A *schematic argument* is a sequence of schematic sentences. A set of *filling instructions* indicates how dummy letters are to be replaced in specific applications. The third component of an argument pattern is a *classification* for a schematic argument, which provides the inferential characteristics of the argument, dividing the schematic sentences between premises, conclusions, and rules of inference.

Unification is achieved by deriving descriptions of many types of phenomena using one or a few argument patterns over and over again. But certain constraints have to be met. Kitcher requires argument patterns to be stringent. The stringency of a pattern is determined by the logical structure imposed by the classification that each instantiation of the pattern must exhibit to count as an instantiation of it, and by the conditions on the substitution of expressions for dummy letters, requiring that each instantiation includes the same non-logical vocabulary. Patterns that are not stringent admit of any derivation to count as an instantiation, and therefore fail to be genuinely explanatory. A theory is said to unify "when it provides one (more generally, a few) pattern(s) of argument which can be used in the derivation of a large number of sentences we accept" (1981: 333). More precisely, the unifying power of a theory positively depends on (i) the *number of conclusions* that can be derived by its argument patterns and (ii) on the *stringency* of the patterns, and (iii) it varies inversely with the *number of patterns* that it employs to derive its conclusions. Note that (iii) should also take into account the similarity between the distinct patterns a theory includes. Sometimes the distinct patterns share a common core pattern, that is, each contains some pattern as a sub-pattern (Kitcher 1981: 521). The unifying power of a theory that contains more than one pattern is enhanced by some or all of its patterns sharing a common core.

We will now see how far this account illuminates the practice of unification in GeoEcon. In 1991, Paul Krugman published an article that was to become seminal for GeoEcon (Krugman 1991). It offers what is generally regarded as the *core model* of GeoEcon. [2] It is the first model that, within a general equilibrium framework, enables the endogenous derivation of the agglomeration of economic activity from the presence of increasing returns to scale and transportation costs[3] giving rise to pecuniary externalities.[4] The endogenous derivation of agglomeration was made possible by the adoption of the Dixit-Stiglitz model of monopolistic competition (Dixit and Stiglitz 1977) incorporating transportation costs and worker mobility. Following Krugman's 1991 contribution, a variety of models has been proposed that extend and modify the core model and apply it to account for various classes of empirical phenomena.

The GeoEcon unification can be seen as the application of a few model types to the explanation of diverse empirical phenomena, provided those apparently different model types are structurally similar. Geographical economist Robert-Nicoud's apt analogy with a common "genome" illuminates:

> An analogy with identical twins is helpful to understand the depth of the similarities among these apparently different models. Like identical twins, they share the same genome (or intrinsic properties). But even identical twins look a bit different and have different characters. Also, they are different individuals who dress up differently. (Robert-Nicoud 2005: 205)

This metaphor of genome is meant to capture the similarity between different model types, or argument patterns that constitute GeoEcon. In Kitcherian terms, we can think of the theoretical genome as a core argument pattern that distinct patterns, or model types, share in common. The *GeoEcon Core Pattern* is the framework provided by the Dixit-Stiglitz model of monopolistic competition plus transportation costs and the presence of mobile factors, enabling the generation of conclusions regarding the distribution of economic activity in space. The GeoEcon Core Pattern enables the derivation of the spatial distribution of economic activity as follows. On the one hand, the more agents there are in a locality, the more attractive that locality becomes for further agents. The simultaneous presence of increasing returns to scale and transportation costs can produce, at the aggregate level, pecuniary externalities. Firms can choose where to locate, and because of

[2] It is the *core* model because it provides the basic apparatus for subsequent models. It is generally regarded as the *first* core model because a second core model has been recently introduced (Fujita, Krugman and Venables 1999; Krugman and Venables 1995, 1996; Puga 1999). By employing a different functional form, the second core model and its refinements solve a few problems that beset the first one such as its bias towards deriving complete agglomeration and its failure to account for the empirical fact that concentration of manufacturing production exceeds concentration of manufacturing labour (Brackman et al. 2001; 2004).

[3] The presence of space implies that the cost of exchanging goods and services across locations increases as (both physical and cultural) distance increases due to physical transport, tariffs, cultural barriers and so on. In GeoEcon, transportation costs are generally assumed to be of the "iceberg form" meaning that only a fraction of the good arrives at destination. This assumption is made in order to avoid modelling a separate transportation sector.

[4] (Positive) externalities are defined as a decrease in average costs as a result of an increase at the level of output of the whole industry. Pecuniary externalities are transmitted through the market via price effects for each firm, which, as a consequence, may decide to change its output decisions. Simply put, their presence implies that the more firms and workers there are in a locality, the more the locality becomes attractive for further firms and workers. The form pecuniary externalities take in GeoEcon can also be referred to as market-size effects, or backward and forward linkages.

pecuniary externalities, they have an incentive to locate in the larger market for their products (whether final or intermediates). Workers benefit from being close to the producers of manufacturing goods, and if they are free to move they choose to locate where wages are higher. On the other hand, the higher number of firms and workers in a locality also means higher competition and higher prices of goods and of factors of production, which reduces the attractiveness of the locality. Whether agglomeration of economic activity takes place will then depend on whether the positive effects of pecuniary externalities outweigh the negative effects of increased competition.

The GeoEcon Core Pattern is embedded in different model types or general patterns used for deriving conclusions about diverse agglomeration phenomena. GeoEcon unification has been mainly effected by the application of two general patterns or model types, the *Core-Periphery pattern* (henceforth C-P pattern) and the *Vertical Linkages pattern* (henceforth V-L pattern), which correspond to the two core models of GeoEcon. The C-P pattern is based on Krugman (1991), which relies on the mobility of labour to derive a core-periphery structure, a situation where the whole of economic activity is located in one area (the core). The V-L pattern is based on Krugman and Venables (1995) and yields agglomeration, trade and specialization at the international level by assuming the presence of input-output linkages between firms.[5] /[6]

In order to obtain the features of a Kitcherian pattern, we reconstruct each model as a template for the derivation of different phenomena in subsequent refinements, extensions and applications. We next provide a schematization of a simple C-P pattern and of a simple V-L pattern that enable deriving the spatial distribution of a sector characterized by the presence of increasing returns to scale (the sector can also encompass the whole of industrial activity). More complex and extended versions of the simple patterns can be construed to derive further types of conclusions. For instance, both patterns can be modified to derive the distribution of economic activity across many locations. Or by assuming the presence of two sectors characterized by increasing returns to scale and using each other's products as inputs, the V-L pattern can be used to explain international specialization, that is, why each of the two sectors agglomerate in a different country.

Our reconstruction of the two patterns formulates their schematic arguments and the associated filling instructions and classifications as follows.

[1] The simple C-P pattern (Krugman 1991)

(1) There are two identical locations: n_1 and n_2.
(2) There are two sectors, A and M.

[5] Some growth models rely on factor accumulation as the foundation for the emergence of the interaction of market-size and competition effects.
[6]. Puga (1999) proposes a model combining input-output linkages and labour mobility. This can be taken to constitute a further general pattern.

(3) A is tied to a location and produces a homogenous good, G_A, under constant returns to scale. M is a monopolistic competitive sector: there is a large number of firms producing, under increasing returns to scale, differentiated products, $g_{m1}, g_{m2}, \ldots g_{mn}$.
(3) Each sector employs a specific factor of production: $\mathbf{L_A}$ and $\mathbf{L_M}$.
(4) $\mathbf{L_M}$ moves across locations in response to changes of its price; $\mathbf{L_A}$ is immobile between locations.
(5) The good produced by M is subject to transportation costs, $\mathbf{1/T}$.
(6) The typical individual in the economy demands both G_A and G_M. The typical individual not only prefers more goods to less, but also prefers a larger range of $g_{m1}, g_{m2}, \ldots g_{mn}$.
(7) M is evenly distributed between n_1 and n_2 under conditions C_1 and is agglomerated in either n_1 or n_2 under conditions C_2. (which amounts to identifying the *break point*, the conditions under which agglomeration becomes possible, and the *sustain point*, the conditions under which agglomeration is sustainable). In particular, **M** agglomerates for low level of transportation costs

Filling instructions. Replace n_1 and n_2 with types (or tokens) of locations (between which labour can move, such as zones within metropolitan areas, regions within a country, or regions involving more than one country, characterized by free mobility of workers such as the European Union). Replace A and M with types (or tokens) of sectors (agricultural, manufacturing, service). Replace L_A and L_M with type of labour specific to each sector (agricultural labour, manufacturing labour, skilled or unskilled labour). Replace C_1 and C_2 with expressions that relate the main parameters to the distribution of economic activity: the share of the mobile factor, the level of transportation costs, the preference for variety).

Classification. (1)-(6) are the premises. (7) is obtained from the set of premises, first by deriving analytically the equilibrium equations, and then using numerical examples to solve them.

The C-P argument pattern can be applied to locations at different levels of spatial aggregation, and to different kinds of sectors in the economy. Suppose we want to explain why all industrial activity is concentrated in one region. Here, the two locations n_1 and n_2 are to be interpreted as different regions, while M is interpreted as industrial activity. If instead we want to explain why the service industry is located in one area within a metropolis, then locations n_1 and n_2 are to be interpreted as different zones of a large metropolitan area, and M as the service industry (Kolko 1999).

Except for premise (4), the schematic argument for the simple V-L pattern is the same as that of the C-P pattern. Here we list only those components that differ from the C-P pattern:

[2] The simple V-L pattern (Krugman and Venables 1995)

…

(4) **M** employs L_M and each other's products $g_{m1}, g_{m2}, \ldots g_{mn}$ as intermediate inputs

Filling instructions. Replace n_1 and n_2 with types (or tokens) of locations (between which labour mobility is limited or absent such as countries or regions involving more than one country) […] Replace **C1** and **C2** with expressions that relate the main parameters to the distribution of economic activity: the level of transportation costs, the share of intermediates in production, and the preference for variety.).

In the V-L model type, premise (4) indicates that $\boldsymbol{M}$ not only employs $\boldsymbol{L_M}$ but also employs as inputs the products of sector **M** ($\boldsymbol{g_{m1}}$, $\boldsymbol{g_{m2}}$, … $\boldsymbol{g_{mn}}$). Remarkably, the expressions from which to derive the conditions under which agglomeration or dispersion occurs (the break and sustain points) are almost identical to those of the C-P model and the conclusions that relate the level of transportation costs to agglomeration are also the same. As the information given in the filling instructions of the two patterns suggest, their instantiations explain different kinds of agglomeration phenomena. Since the C-P argument pattern assumes labour, $\mathbf{L_M}$, to be mobile, it can be used to explain the distribution of economic activity in systems where labour can relatively freely move across locations, whereas the V-L pattern can be used to explain phenomena where this is not the case.

These simple versions of the C-P and V-L patterns portray GeoEcon as comprising the repeated applications of a few argument patterns, some of which are similar in virtue of sharing a common Core Pattern. Increasing effort has recently been devoted not only to extending the number of conclusions about spatial phenomena that can be derived, but also to unifying different types of models into a single mathematical structure (e.g. Robert-Nicoud 2005; Ottaviano and Robert-Nicoud 2006; Pflüger and Südekum 2006, 2008). Showing that all the model types share a common stringent Core Pattern can increase the unifying power of GeoEcon by simultaneously acting on Kitcher's conditions (ii) and (iii). Developments in GeoEcon have thus pushed towards raising the unifying power of the theory by increasing three things: the number of conclusions, the stringency of the patterns, and the similarity of the patterns.

3. Mathematical structure *versus* ontological conviction?

Geographical economics is said to be one outcome of the "monopolistic competition revolution" in economics, which started unfolding after the appearance of the Dixit-Stiglitz model of monopolistic competition in the field of industrial organization (see Brakman and Heijdra 2004). The Dixit-Stiglitz model offered a mathematical tool with which to deal with the consequences of increasing returns at the firm level. Its workability and analytical flexibility allowed its application to a number of different areas of inquiry. New trade theory, new growth theory and geographical economics all developed as applications of the Dixit-Stiglitz model to their specific fields of inquiry. In particular, a sequence of successive extensions to models of new trade theory resulted in the appearance of the first GeoEcon core model that only adds transportation costs and factor mobility to its international trade antecedents (Krugman 1979, 1980 and Krugman and Venables 1990). Thanks to this addition, the size of the market can be endogenously derived from the agents' locational choices, and trade models are turned into models of the agglomeration of economic activity.

The Dixit-Stiglitz model of monopolistic competition cum transportation costs and factor mobility constitutes the Core Pattern of GeoEcon models (although some attempts have been made to model imperfect competition differently). The mathematical framework employed by GeoEcon has played a crucial

role in the dynamics of unification: its repeated application to a host of phenomena, often with only slight modifications, is precisely what has produced the celebrated unification. As noted above, there has been a major pursuit of a single mathematical framework, of which particular models are special versions. This testifies for the important role that mathematics plays in unification.

This feature of GeoEcon is in line with Morrison's observation that in many instances of unification in physics and biology the unifying theory embodies a mathematical structure that has a prominent function in the process of unification. But Morrison also makes the stronger claim that sometimes this happens at the expense of ontological considerations: not only does a certain mathematical structure or formalism serve as a unifying tool, but the unification itself is a product of the mathematics rather than of a causal hypothesis regarding the relations between diverse phenomena (Morrison, 2000, 109-110). We now ask whether this stronger claim characterizes the GeoEcon case.

First, consider the following passage.

> What we find remarkable and gratifying in all of this is the extent to which we are able to use the same modeling "architecture" to address so many issues in seemingly disparate fields. But then our point is precisely that these fields are not that disparate after all: be it urban economics, location theory, or international trade, it's all about where economic activity takes place - and why" (Fujita et al. 1999: 12)

What is here referred to as the "same modeling architecture" relates to the abstract mathematical structure. However, at the same time, Fujita et al. (1999) seem to entertain the idea that unification achieved by applying the same modelling architecture to "seemingly disparate fields" is ontologically grounded: "the fields are not disparate after all" in the sense that they all describe the same generic aspects of how things are in the world, namely "where economic activity takes place - and why". A similar point is made even more clearly in the following quote.

> The empirical phenomena touched upon above have been studied thoroughly from many different angles, based on different theoretical frameworks, for a long time.[…] We have already mentioned that the fractal nature of location phenomena […] suggests that *similar forces* might be relevant in explaining them. We *therefore* use throughout the book a common structural approach to help understand the phenomena […] (Brakman et al. 2001: 17-18; emphases added)

The unification of the phenomena studied separately by previous theories has been achieved with the aid of a "common structural approach". Yet it is the fractal nature of agglomeration, namely that it repeats itself at various scales of spatial resolution, which suggests the ontological conjecture that "similar forces might be relevant" in explaining the phenomena. There are two sets of such forces, pulling in opposing directions: the "centrifugal forces" and the "centripetal forces". The theoretical practice of GeoEcon consists of explaining

the spatial distribution of economic activity as an outcome of the interplay between these two sets of forces. The centripetal forces consist of pecuniary externalities. The centrifugal forces are constituted by market competition, higher input prices, and the costs due to congestion. Agglomeration of economic activity arises when the centripetal forces are stronger than the centrifugal ones. The description of how these forces arise and how they interact so as to produce agglomeration represents what we call the *GeoEcon Agglomeration Mechanism*. GeoEcon models are about variations of this causal mechanism, and GeoEcon unifies phenomena in terms of these mechanisms on the presumption that similar forces and mechanisms are at work in producing apparently diverse phenomena (cf. Marchionni 2004, 2006).

We conclude that both ontological and mathematical considerations have played a role in the unification project of GeoEcon. So there has not been any conflict or tension between the two. Thinking of how things have evolved in GeoEcon, we might characterize their respective roles by saying that unification has been *motivated* by ontology and *facilitated* by mathematics (even though we admit there is no sharp dichotomy between facilitation and motivation). On this account, ontological conviction (or conjecture) and a suitable mathematical framework have both been necessary for GeoEcon unification.

This qualification also serves to mark the difference between GeoEcon theoretical *unification* and the previous applications of the Dixit-Stiglitz model in the fields of industrial organization, growth theory and trade theory. In these earlier applications, a common mathematical framework that allowed the treatment of increasing returns in a general equilibrium setting had been used for studying different phenomena in different fields. The virtues of the Dixit-Stiglitz model such as flexibility and workability were acknowledged, but the only commonality among the phenomena explained was held to be the presence of increasing returns at the firm level and imperfect competition between firms. This did not yet provide any strong sense of ontic unity among the phenomena. Unsurprisingly then, at this earlier stage no conjecture had actually been made regarding an underlying unity, and there was no talk of unification of phenomena among economists. The excitement and growing confidence around unification emerged together with GeoEcon's claims about the common causal structure of various domains of phenomena. The unification pursued by GeoEcon was facilitated by the formal Dixit-Stiglitz apparatus, but its claims to unification were ultimately motivated by ontological considerations.

There is another important aspect of the relation between mathematics and ontology that deserves attention. This is that the requirements of mathematical tractability associated with a specific mathematical structure might have become a straightjacket that inhibits or impedes attempts to capture the unity that is conjectured to obtain among the phenomena. In our case, this is not just a speculative possibility. Not only is this one of the oft-made criticisms against GeoEcon, but geographical economists themselves admit of the possibility of such mathematical restraint. They acknowledge that some of their assumptions are indeed the result of considerations of mathematical tractability - "modelling tricks" as they call them (Krugman 1998; Fujita et al. 1999) - and that the reliance on these modelling tricks can endanger the theory's capacity of

adequately representing the unity in the world. For instance, a major representative admits that "the new economic geography […] suffers to some extent from the temptation to focus on what is easiest to model rather than on what is probably most important in practice." (Krugman 2000: 59).[7]

It is not clear what precisely the epistemic risks due to the modelling tricks are envisaged to be, so we must suggest a couple of possibilities. First, the models might fail to adequately capture the real working of the agglomeration mechanism that unites the phenomena. Second, the models might fail to accurately explain or predict since much of what might be relevant is left out. The first scenario is the most problematic as it casts doubt on the whole unificatory project. If mathematical tractability imposes so restrictive requirements that the real working of the unifying mechanisms cannot be captured, then we should conclude that the GeoEcon unification is just an artefact of the mathematical framework. Empirical investigation, which is relatively underdeveloped (cf. Fujita et al. 1999 and Brakman et al. 2001) should help to establish whether the phenomena GeoEcon seeks to unify are in fact united in the way depicted. The second scenario concerns the explanation and prediction of specific agglomeration phenomena that are the result of the interplay of a large variety of factors that cannot be easily incorporated in the stylised models of GeoEcon. In this case, in order to salvage the GeoEcon unificatory achievements, we need to decouple unification and explanation, and to distinguish between the explanation of generic patterns or stylized facts and the explanation of particular occurrences. By doing so, we can conclude that GeoEcon seeks to provide a unified explanation of a host of generic patterns or stylised facts. More on this in section 5.

These observations have further philosophical implications. As soon as geographical economists concede the possibility that due to the employment of highly unrealistic models the unifying theory might fail to adequately describe a real unity or to depict the precise working or relative relevance of the mechanisms underlying it, they come to reveal a realist attitude towards their models. They think that there are pre-theoretic (or pre-GeoEcon) reasons to believe that there is unity among the phenomena studied, but that the theoretical constraints employed in order to capture that unity may in the end lead the endeavour astray. This exhibits an implicit commitment to both realism (about the existence of common mechanisms) and fallibilism (about the possibility of one's models not getting those mechanisms quite right). If we are correct in this interpretation, then unity among the phenomena is taken to be prior to, and independent of, their theoretical unification. This feature of GeoEcon practice runs counter to Kitcher's position on which unity amongst phenomena is a function of a unifying theory. On his account, the notion of explanatory relevance has no other sense than that of "figuring in the systematization of belief in the limit of scientific inquiry, as guided by the search for unification" (Kitcher 1989: 499). Geographical economists appear to disagree.

[7] There are ongoing debates in economics and neighboring fields over the use – or, as some believe, overuse or misuse - of mathematics in conventional economics. The dispute between geographical economists and economic geographers has also partly concerned this aspect of geographical economics. We don't enter this debate here. See our contributions to the essay symposium in *Environment and Planning A*, volme 36, number 10 (October 2004).

4. Derivational unification and ontological unification

In line with the empiricist tradition, Kitcher has sought to cash out a notion of unification as devoid as possible of a metaphysical load. However, unification needs not be so conceived. One should distinguish between two broad types of unification: derivational unification and ontological unification (Mäki 1990, 2001). Kitcher's account describes a version of derivational unification, while ontological unification goes along with accounts of explanation that stress the importance of representing objective relations of constitution and causation in the world. Relevantly for our case, the latter can be associated with causal-mechanical views of explanation, for example those from Railton (1978) and Salmon (1984, 1998) to Machamer, Darden and Craver (2000).

Derivational unification is a matter of deriving large classes of explanandum sentences from a parsimonious set of premises, theoretical structures or inferential patterns. It is based on the derivational capacities of theories and models. Per se derivational unification does not imply anything about unification-independent unity among the phenomena themselves. By contrast, ontological unification is based on the representational capacities of theories and models in depicting underlying real systems. Theories are regarded as purportedly true pictures of the simplest structures, mechanisms, and processes of the world's workings; phenomena are regarded as manifestations thereof. Ontological unification is a matter of discovering a real unity in the world by way of redescribing apparently independent and diverse phenomena as manifestations (outcomes, phases, forms, aspects) of one and the same small number of entities, causes, mechanisms, processes (Aronson 1984; Mäki 1990, 2001).

In certain cases the two kinds of unification can coincide. A theory might be conceived as unifying in virtue of unravelling the real unity among the phenomena, and achieving this by way of applying the same pattern of derivation to the explanation of diverse phenomena. In this sense, we would have a case of derivational unification with ontological grounding. This is what seems to be going on in our case. Recall that the abstract mathematical structure of the Dixit-Stiglitz model cum transportation costs and mobility of factors has played a substantial role in the process of unification in that it has facilitated the treatment of diverse economic phenomena within a unified framework. On the other hand, in pursuing unification, geographical economists were driven by the belief in an underlying unity among the phenomena, a unity that the mathematical structure made possible to uncover. It is therefore not surprising that GeoEcon unification is not considered solely a derivational accomplishment; the aim is rather to establish a significant fact about the world: agglomeration at different spatial scales can in fact be caused by the same basic forces interacting so as to trigger similar mechanisms – those constituted by the interplay between centripetal forces and centrifugal forces. The derivational structure of the theory is intended to capture this independent causal structure. Talk of "mechanisms" and "forces" is frequent in GeoEcon as the following quotations exemplify.

> The main reason for looking at these different levels of aggregation is that in explaining clustering, geographical economics shows that to a large extent the *same basic forces* apply at all levels of aggregation. (Brakman et al. 2001: 2; emphasis added)

> […] geographical economics is able to show that the *same mechanisms* are at work at different levels of spatial aggregation. […] *the same underlying economic forces are relevant for explaining* the spatial organization of cities, the interaction between regions within a nation, as well as the uneven distribution of GDP across countries […]. (Brakman et al. 2001: 323; emphasis added)

This talk about the "same mechanisms" and the "same forces" not only supports a view of unification that is consistent with the ontological variant, but also connects with the issue of the role of real mechanisms in explanation. In this respect, it seems to speak the language of Salmon and his allies rather than that of Kitcher.[8] On the Salmonian conception, explaining a phenomenon is a matter of laying bare the mechanisms or causal processes that underlie the phenomena we observe and wish to explain (Salmon 1984, 1998). The mechanistic view of explanation is grounded on the realist thesis that the world has a causal structure independent of our explanatory efforts; Kitcher's view of explanation instead leaves no room for independent metaphysical concepts such as that of mechanisms.

The idea of a derivational unification with ontological grounding comes close to Salmon's suggestion (1998) that the causal-mechanical and the unification views of explanation could be reconciled if scientific unity was seen as a product of delineating "pervasive causal mechanisms". Skipper (1999) expands on Salmon's suggestion and proposes that explanations that unify empirical phenomena proceed via the application of schematized causal mechanisms, or "mechanism schema". In GeoEcon, what is believed to bind different kinds of agglomeration phenomena together and allow their treatment within a unified framework is, as we have seen, the presence of common causal mechanisms. It then makes sense to view the theoretical unification offered as the successive application of a mechanism schema to phenomena at different spatial scales so as to establish the ontic unity between these kinds of phenomena. In other words, what the core model of GeoEcon laid down and successive applications to diverse phenomena retain is a schematized causal mechanism: the presence of increasing returns, transportation costs and mobility of factors giving rise to forces pushing in opposite directions – the centripetal and centrifugal forces – whose equilibrium determines the distribution of economic activity in space.

[8] Kitcher (1989) admits that scientists often do not explicitly justify their causal judgments by recognizing the argument pattern that best unifies. This implies that looking at actual scientific cases of unification may not be helpful in determining whether derivation or causation comes first. Since our aim is to describe actual scientific practice and obtain philosophical insights from it, we are justified in relying on geographical economists' views, and leave it to others to demonstrate that in fact the talk of mechanisms and forces that occur in GeoEcon is nothing more than mere talk.

5. Explanation *versus* unification?

The relationship between unification and explanation has been one of the key issues in the philosophical literature on unification. Whereas Kitcher takes unification as tantamount to explanation, the causal mechanical view takes explanation to be a matter of identifying causal mechanisms, whether singular or general. On this latter account, explanation is not unification, although in some cases the two are conjoined; in such cases unification may come as an extra bonus.

What can we infer from GeoEcon practice regarding this issue? In the previous sections, we have shown that while selected aspects of unification in GeoEcon largely conform to aspects of Kitcher's account of unification, geographical economists appear to dissociate theoretical unification from real-world unity: they admit that the theory might actually fail to capture the real unity among the derived phenomena. We have also seen that it makes sense to view GeoEcon as offering both derivational unification, effected through the application of the same argument pattern, and ontological unification, which is the consequence of those patterns representing schematized common causal mechanisms. If we take this to be unification in GeoEcon, we also need some idea of explanation in GeoEcon in order to determine its implied view of how unification and explanation are related.

A major general notion of mechanism prevalent in economics involves the idea of rational economizing activity by economic agents. Explaining a kind of phenomenon means tracing its 'microfoundations' in such activity. In many characteristic cases of economic explanation, phenomena are explained by representing them as unintended (invisible-hand) consequences of interactive individual choices. We find this principle also in GeoEcon. Indeed, practitioners of GeoEcon identify the endogenous derivation of agglomeration from fundamental micro-economic parameters as the genuinely explanatory component of their theory and as a novel achievement.

> By explicitly modelling the choices of firms, consumers, and workers in a general equilibrium framework, within a market structure of imperfect competition, geographical economics is the *only* field which provides a micro-economic foundation in a consistent general equilibrium framework for the spatial distribution of economic activity. (Brakman et al. 2001: 323)

The key idea is that micro-foundations provide the mechanisms and are needed for genuine explanation. In contrast to earlier theories, "Geographical economics shows how in such a world [of increasing returns to scale] the decisions of individual economic agents may give rise to clustering or agglomeration" and thereby helps understand "the *why*, *who* and *where* of the location of economic activity" (Brakman et al. 2001: 323). The stress on "the why, who and where" is very much in the spirit of contemporary thinking of explanatory mechanisms. GeoEcon explains the agglomeration of economic activity by deriving it endogenously from – by representing it as an unintended consequence of - the choices of firms, consumers and workers. This also

amounts to answering how-questions, questions of *how* agglomeration emerges. Krugman (1995) draws an analogy with geology before the discovery of ocean spread and plate tectonics: geologists knew a great deal about the erosion of mountains, but could not explain why mountains existed at all. Similarly, before the dawn of GeoEcon, economists and geographers knew a lot about the economic advantages of spatial agglomerations, but were unable to explain *how* agglomerations would come about and be sustained as a consequence of the choices of economic agents. For instance the problem with theories in regional economics (say central place theory) is that they merely *rationalize* the kind of agglomeration they study (say the existence of a hierarchical system of cities) rather than explaining it precisely because they do not address the question of how the actions and interactions of individual economic agents lead to the outcome (Brackman et al. 2001: 32-36). [9]

These remarks suggest that for geographical economists, what makes their theory genuinely explanatory is the invocation of micro-foundations – not the fact that the theory unifies. Rather than unification being the source of explanation, the provision of micro-foundations is believed to be the source of *both* explanation (as a product) and unification (as a side product). To explain an agglomeration phenomenon is to represent it as an unintended consequence of individual choices, that is, to reveal its microfondations. In order to explain one, or one kind of, agglomeration phenomenon, it is not required that many kinds of agglomeration phenomena are unified with one another. Unification comes as an extra bonus in case the same micro-economic mechanisms can be shown to underlie apparently different agglomeration phenomena. This bonus is very highly regarded by geographical economists, but this entails nothing about the possibility of singular explanation. For geographical economists, explanation and unification are not the same.

Consider now Morrison's more radical view that not only is explanation different from unification, but "the very project of unifying two theories is, for the most part, at odds with the procedures necessary for obtaining detailed explanatory knowledge" (Morrison 2000: 192). She seems to suggest a trade-off conceived in terms of the general and the particular, and the associated degree of detail.

> The more general the hypothesis one begins with, the more instances or particulars it can, in principle, account for, thereby "unifying" the phenomena under one single law or concept. However, the more general the concept or law, the fewer the details that one can infer about the phenomena. Hence, the less likely it will be able to "explain" *why particular phenomena* behave as they do. If even part of the practice of giving explanation involves describing *how and why particular processes occur*—something that frequently requires that we know *specific details about the phenomena* in question—then the case for separating unification and explanation becomes not just desirable but imperative. (Morrison 2000: 20; emphases added)

[9] To characterize the state of agglomeration theory before GeoEcon, Krugman et al. (1999) reports the anecdote of a physicist who incredulously remarked: "so you are telling me that agglomerations exist because of agglomeration economies?"

It is unclear what exactly is being suggested here, but it seems Morrison proposes inferring from lack of detail to lack of explanatory power; for unification misses detail while explanation requires detail. As it happens, the premise of this argument is explicitly acknowledged in the GeoEcon literature: practitioners admit that unification in GeoEcon has been achieved at the expense of neglecting details specific to particular phenomena.

> By using highly stylized models, which no doubt neglects a lot of specifics about urban/regional/international phenomena, geographical economics is able to show that the same mechanisms are at work at different levels of spatial aggregation. […] In order to lay the foundations for a unified approach, there is a price to be paid in terms of a neglect of institutional and geographical details. (Brakman et al. 2001: 323)

While the connection between unification and neglect of detail is evident, it is less obvious that another "price to be paid" is loss in explanatory power in any general sense. Indeed, the GeoEcon case speaks against the latter kind of trade-off as we will next show. To do this, we must pay some attention to aspects of explanation: as reviewers have also noted (Ladyman 2003; Muller 2001), Morrison's argument is rather vague because she has not provided a precise notion of explanation.

Our first observation stresses the importance of the precise identity of the explanandmum for the assessment of any purported explanation. Explanatory information can be sought at various levels of abstraction and resolution, and these are determined by the degree of resolution at which the explanandum itself is described (e.g. Garfinkel 1981; Lewis 1986). That this feature of theories and explanations is well recognized by economists is evident in the established idea that economic theories typically explain what they call "stylized facts" rather than singular events in their particularity. Indeed, it is GeoEcon's concern with explanations of stylized facts that partly accounts for the fact that GeoEcon abstracts away from a host of specific details. Stylized facts are abstractions and modifications of more detailed bodies of particular information: they are generic patterns rather than particular occurrences. Examples of stylized facts GeoEcon aims to explain include, "Trade is large between similar countries and dominated by intra-industry trade" (Brakman et al. 2001: 245), and "In nearly all countries, cities largely specialized in a few activities coexist with much more diversified cities" (Duranton and Puga 1999: 2). To explain stylized facts is different from explaining particular bodies of data, as the latter requires more information about the details of the particular case, and these details differ from case to case (cf. Halonen and Hintikka 1999). The generic GeoEcon Agglomeration Mechanism is to be supplemented with a host of specific details when employed to explain particular events such as the establishment of a hierarchical system of cities in the US by the 1870 (Fujita, Krugman and Mori 1999) or the existence of particular industry clusters today, such as Silicon Valley. The abstraction from specific details may very well limit the explanatory ambitions of GeoEcon with respect to those particular occurrences; and the introduction of some such details might require major modifications of

the theoretical framework, or such details might even resist integration within the straightjacket of the GeoEcon framework. While we admit these possibilities, our conclusion is that failure to explain particular occurrences does not as such imply failure to explain generic patterns or stylized facts. Unification does require abstraction from particular details, but does not rule out explanation of generic patterns in terms of generic mechanisms.

Granting that explanations often concern generic patterns, a similar suspicion of a trade-off can be raised: in order to unify classes of generic patterns, one is forced to gloss over their distinguishing characteristics, which somehow results in a loss of explanatory power. In our case, this means, for example, bracketing those features of industry clusters (geographic concentration of firms in the same or related industry occurring at relatively small spatial scales) and core-periphery patterns (involving several industries and occurring at larger spatial scales) that distinguish these two classes of generic patterns from one another. One is then unable to explain specific characteristics of the two classes of patterns. Again, our response is that this does not necessarily result in any *general* loss of explanatory information. The unifying core model may be able to explain what those classes of patterns share in common, while explaining their distinguishing features will require incorporating specific information about those classes.

So there is no *general* trade-off between explanation and unification. There is a genuine trade-off at most between certain degrees of unification and certain kinds of explanatory information. There are various kinds of explanatory information worth having, and there may be trade-offs between them. One such kind concerns what is common among apparently different classes of phenomena, while other kinds of information highlight what is distinct to those classes. [10] Explanations that only focus on the causal details of specific phenomena will obscure what those phenomena share in common (see for instance Sober 1999).

Yet another version of the alleged trade-off between explanation and unification focuses on the explanans. One of Morrison's ideas seems to be that we often have a unifying mechanism but no account of how the mechanism operates in bringing about the unity among phenomena, which results in deficient explanations (Morrison 2006). Again, GeoEcon does not provide an instance of this sort of trade-off. Recall that in GeoEcon, agglomeration is endogenously derived from micro-economic considerations; by opening up what was previously treated as a black box and revealing the micro mechanism inside the box, diverse empirical phenomena have been revealed to be of the same kind. Details about the unifying mechanism -- about the ways in which the actions and interactions of economic agents faced with locational choices produce diverse empirical phenomena -- revealed that the same kind of mechanism could be involved. One could of course argue that the micro-foundations provided by GeoEcon are not adequate, or that micro-foundations do not ensue in genuine understanding or explanation. We do not deny any of these possibilities. It is nonetheless

[10] Plutynski (2005) notices that Morrison (2000) fails to recognize the variety of kinds of information. Morrison (2006: 242) however denies this. We do not take issue on this except to restate that her claims in Morrison (2000) would have been somewhat clearer had she explicitly provided an account of explanation.

important to appreciate that on economists' own standard of explanation, it is in virtue of the improved account of how the underlying mechanism works that unification itself has been achieved. We conclude that the presumed explanatory power of GeoEcon is not at odds with its unifying power.

6. Multiple mechanisms and degrees of explanatory unification and of ontic unity

We have learnt quite a lot about what practitioners of GeoEcon might mean when they say they have achieved unification of agglomeration phenomena. In order to construct a unifying explanation, GeoEcon abstracts from a host of specific details relevant to explaining particular instances of the phenomenon. This much is obvious and unsurprising. But there is a very important further feature that challenges available accounts of unification. This further feature is a cause of challenge – some may find it a source of embarrassment. As is clear both to geographical economists and their opponents, the kind of mechanisms that purportedly unify the various agglomeration phenomena are usually neither the only nor even the main mechanisms responsible for the actual distribution of economic activity in space: there are many other contributing and inhibiting mechanisms in operation. For instance technological externalities, that is, externalities that affect firms directly rather than via the market, are systematic forces that push towards agglomeration. The long list of yet other possible factors would include natural geographical characteristics of locations; cultural, social and institutional mechanisms; and macro-economic and political changes.

Given that GeoEcon only captures a small portion of these possible contributing and inhibiting factors, we should ask to what extent GeoEcon really represents a case of explanatory unification. To answer this, we propose to introduce and utilize the twin ideas of degrees of explanatory unification and degrees of ontic unity. *The degree of explanatory unification* is a function of the range of kinds of phenomena that the mechanism (or the theory depicting it) governs. *The degree of ontic unity* is a function of the firmness of the hold with which the mechanism governs the phenomena. We can then identify the following possibilities when explaining a phenomenon of agglomeration.

1. The unifying mechanism is always the only mechanism in operation.
2. The unifying mechanism is not always the only mechanism in operation but it is always the main mechanism in operation.
3. The unifying mechanism is not always the only mechanism in operation and is not always the main mechanism but is always in operation.
4. The unifying mechanism is not always the only mechanism in operation, is not always the main mechanism, and it is not always in operation in all instances of the classes of phenomena it unifies.

As we descend from the top to the bottom of this simple taxonomy, two things happen. On the one hand, the unifying power of the mechanism (or the theory depicting it) will increase because an increasing number of kinds of phenomena is likely to be governed by it. On the other hand, the strength of ontic unity amongst the phenomena will decrease because the firmness of the hold with which the mechanism governs the kinds of phenomena becomes weaker.

Of the four cases, 1 and 4 are the most interesting and problematic. Consider case 1 in which the GeoEcon Agglomeration Mechanism is the only mechanism in operation. It is hard – if at all possible – to find cases like this in the real world. But in GeoEcon this is a standard feature that has been built into its models. In GeoEcon models – in those radically simplified imagined worlds - the GeoEcon Agglomeration Mechanism is sufficient to the emergence and sustenance of agglomeration in locations at different levels of aggregation that are at the outset identical. No further mechanisms are needed for the causation of agglomeration to be in operation. Put the mechanism that works through pecuniary externalities in place, and what emerges is agglomeration. In regard to the imagined simple GeoEcon model worlds, the unification of agglomeration phenomena is complete: those model worlds are all versions of our case 1. This may give assurance to the practitioners of GeoEcon that high degrees of unification have been achieved. But with respect to real world instances of agglomeration, the degree of unification remains relatively low in the sense that few if any such instances are actually and strictly speaking covered. Thinking of the strength of ontic unity, it is no doubt very high in the GeoEcon model worlds and in those few real world cases that are close to situation 1.

Cases 2 and 3 are typical of real world agglomeration. In reality, the GeoEcon Agglomeration Mechanism rarely (if ever) acts alone and may not even be the main mechanism at work in every case. As geographical economists themselves openly point out, in certain cases, for instance cities, technological externalities arising from physical proximity are likely to be more relevant than market size effects in pushing towards agglomeration. In regard to these two types of case in our taxonomy, we are nevertheless prepared to say that unification (of varying degrees) takes place.

Case 4 is the most problematic of them all. The GeoEcon Agglomeration Mechanism might indeed not be necessary for agglomeration; in principle, agglomeration may be a chance occurrence or perhaps the outcome of the design of a planning agency, or exclusively an effect of technological externalities. Naturally, we may be hesitant to say that in this case unification happens at all: the mechanism simply fails to unify those phenomena with respect to which it plays no causal role. In other words, if the mechanism fails to govern particular members of a class of phenomena, then it fails to unify that class with other classes. On the other hand, we might try to accommodate this case by extending the idea of degrees of unification. We may simply say that the higher the proportion of members in a class of phenomena that are governed by the mechanism, the higher the degree of unification (and of unity) between this class and others. Thus, the higher the proportion of all cities and all industry clusters that are really governed by the GeoEcon mechanism, the

higher the degree of unification by GeoEcon of cities and industry clusters – even though not all cities and clusters are governed by the mechanism. Note that this presupposes that criteria of membership in such classes are independent of the mechanisms that govern the member phenomena.

We should add that there is nothing very dramatic about this situation, given that in economics and in the social sciences more widely, general claims characteristically admit of exceptions. This suggests that the kind of unification pursued and achieved by GeoEcon unifies large classes of phenomena while permitting relatively weak ties of ontic unity among them. However, it seems obvious that there must be limits to the permissible proportion of exceptions – or to the weakness of ontic unity – otherwise any talk about explanatory unification will become meaningless. It seems equally obvious that given the way GeoEcon practitioners talk about unification as one of their major intellectual achievements, they believe that the phenomena they seek to explain actually stay within those limits.

These observations naturally lead to a brief remark on inter-theoretic and inter-field relations. In an ideal case, a theory that unifies kinds of phenomena also unifies theories and research fields that previously dealt with those classes of phenomena. Agglomeration phenomena have in fact been previously "studied thoroughly from many different angles, based on different theoretical frameworks for a long time" (Brakman et al. 2001: 17-18) – such as trade theory, growth theory, urban and regional economics, and economic geography. Now in the last three cases 2-4 of our taxonomy the phenomena of agglomeration are governed by multiple mechanisms, not just by the GeoEcon unifying mechanism. This implies that the explanation of those phenomena (or many stylized facts about them) will require multiple theories to supplement GeoEcon. The set of such supplementary theories is likely to include also the unificandum theories: those whose domains GeoEcon has sought to unify. GeoEcon cannot (and does not claim to) derive all the phenomena or stylized facts that previous theories can separately cover. To give an example, GeoEcon can be used to derive some of the stylized facts about economic growth (e.g. the fact that countries experience long periods of stagnation followed by rapid growth, and the fact that there are frequent changes in economic rankings among nations), but not others (e.g. persistent rising income levels for almost all countries, and persistent growth differences among countries) (Brakman et al. 2001: 286-287). The various inter-theoretic relations that emerge when combining the explanatory resources of the unificans and unificandum theories are bound to be somewhat complex, but what seems clear is that no complete unification of those theories and fields by GeoEcon is forthcoming in the foreseeable future. They will, and should, retain an explanatory role, otherwise major gaps in the range of explananda will emerge beyond the reach of GeoEcon explanation. But this is a subject for another study.

7. Conclusion

Explanatory unification has played an important role in the development of GeoEcon. With the aid of existing accounts of unification in the philosophy of science we have highlighted aspects of the structure of explanatory unification in this specific context. This has also helped highlight limitations in those philosophical accounts.

We discovered that, by and large, Kitcher's account fits the way in which the GeoEcon unification has been effected: similar model types sharing a common core pattern have been repeatedly applied to different kinds of explanandum phenomena. Our case also lends support to Morrison's claim that unification in science often proceeds with the aid of an abstract mathematical structure. The Dixit-Stiglitz model provided the versatile mathematical framework for dealing with a host of phenomena in different fields, and in the GeoEcon case it functioned as the vehicle through which the unification was achieved. But the driver behind the pursuit of a unified theory appears to be the hypothesis that similar forces and mechanisms are responsible for the occurrence of diverse classes of phenomena. Unlike some of Morrison's cases, unification was the joint product of both mathematics and ontology.

Although the Kitcherian account provides a useful model for the structure of unification of GeoEcon, it fails to capture several important features of it. First, unification in GeoEcon has proceeded by showing how the same causal mechanisms and forces, being at work at different spatial scales, can produce different kinds of phenomena. Second, geographical economists are prepared for the possibility that the mathematical structure has imposed excessively severe constraints on unification such that the outcome might not adequately capture the real unity in the world. This gives us a picture of unification in GeoEcon put forth in terms of mechanisms that exist independently of explanation and unification. Third, geographical economists do not identify the explanatory capacity of their theory with its power to unify but rather with its capacity to derive the spatial distribution of economic activity from – or to represent the spatial distribution as an unintended consequence of - the choices of economic agents. This suggests that unifying power and explanatory power are held to be conceptually separate. But in contrast to Morrison's claim, in GeoEcon unifying and explanatory powers are not at odds, instead the two are joined and proceed together. This is so because it is precisely by means of opening up the black box accommodating the GeoEcon Agglomeration Mechanism that apparently different phenomena were shown to be of the same kind.

The GeoEcon case is hard to accommodate by standard accounts of scientific unification for yet another reason. Although GeoEcon can be seen as unifying phenomena, it is less clear that it can be seen as unifying the theories that previously dealt with them. The reason is that the GeoEcon unifying mechanism is in many cases of real-world agglomeration neither the only nor the main mechanism in operation. This suggests that GeoEcon is offering a high degree of explanatory unification, but a low degree of ontic unity among the unified phenomena.

With some conceptual adjustments, we have been able to identify and describe a special kind of unification in one recent branch of social science. Although none of the philosophical accounts we consulted fully captures the kind of unification characteristic of GeoEcon, each of them has enabled us to highlight some of its aspects. This provides further confirmation to the view that unification in science is not uniform but rather adopts different forms and strategies depending on the peculiarities of the unified domain and on disciplinary contingencies.

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